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MATHEMATICAL SIMULATION OF USING DECOYING AND KILLING MISSILES TO COUNTER ANTI-RADIATION MISSILES

by

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MATHEMATICAL SIMULATION OF USING DECOYING AND KILLING MISSILES TO COUNTER ANTI-RADIATION MISSILES

Authors: Zhou Shuigeng, Tao Benren

(The Eighth Design Department of the Shanghai Academy of Spaceflight Technology)

Abstract: A new method of intercepting anti-radiation missiles (ARM) using decoying and killing missiles (DKM) is proposed in this paper. [Decoying and killing missiles are actually surface-to-air missiles with their guidance heads replaced by decoying jammers.] A mathematical model is set up to carry out a mathematical simulation of the physical process of using DKMs to intercept ARMs. Simulation results show that this plan is theoretically feasible.

Key words: Anti-radiation missile (ARM), decoying and killing missile (DKM), mathematical model, simulation

1. Summary

As everyone knows, ARMs are the most serious threats faced by the radars in antiaircraft weapon systems.[1, 2] Research of effective anti-ARM technology and methods is an extremely urgent task for the field of electronic countermeasures today. At present, the primary technological methods for countering ARMs are hard kill and decoying. Because hard kill requires radars to continuously detect and track targets as small as ARMs, there are high technological demands on radars. Since decoying, on the other hand, requires that the decoying signals correspond to radar signals' power and be synchronous in time, space, and frequency domains, it is also difficult to achieve this through engineering. For this reason, to combine the technological characteristics of hard kill with those of decoying, this paper proposes a mixed anti-ARM plan, which is the decoying and killing anti-ARM method. This method, when taken as

a whole, is a hard-kill method, but in the process of hard killing, it employs decoying technology. To theoretically verify the feasibility of this plan, a mathematical model of the physical process of interception of an ARM by a DKM was set up, and initial mathematical simulations were carried out on this basis. Simulation results show that this design program is feasible in theory, and that further development of relevant theory and experimental research work are worthwhile.

2. Plan Design

Three generations of ARMs have been developed up to now, and the fourth generation of ARMs is in the midst of development. In comparison with the first and second generations of ARMs, the third generation (that is, HARM, which is the most advanced ARM now in service) has the following salient characteristics[3, 4]: a broad-band passive guidance head (working frequency 0.8–20 GHz); high speed (maximum flight speed greater than Mach 3); multiple guidance modes (and thus a certain anti-shutoff capability); and multiple battle tactics (primarily self-defense, opportunity, and preprogrammed methods). This shows that there is a high level of technical difficulty involved for antiaircraft weapon systems to counter HARM attacks. But, through comprehensive analysis of every aspect of relevant ARM technology data and battlefield usage, one can see that:

a. Although ARMs have many modes of operation, the one most often used in actual practice is still the direct hit method. ARMs have a relatively short launch distance, about 20 to 30 kilometers, and their trajectories basically follow the radar beam. Because this mode of operations has the highest hit probability, it is the most effective;

b. Even though modern ARMs employ composite guidance modes, the primary one is still passive microwave guidance. Thus, it is possible

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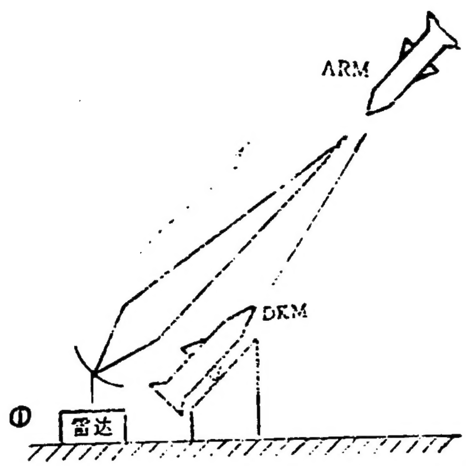
to use false radar signals (also called jamming signals) to carry out decoying and deception against an ARM's guidance head.[5]

On this basis, with low-to-medium altitude missile weapon systems as a background and HARMs as targets, this paper proposes a hard-kill plan of using DKMs to decoy and intercept ARMs. Its goal is to counter ARMs that attack antiaircraft weapon systems [and their] guidance

radar stations. In this plan, DKMs are actually low-to-medium altitude surface-to-air missiles, but their guidance heads are replaced by jammers. Thus, they are either unguided missiles or guided missiles which fly according to predetermined parameters. The signals radiated by the jammers on board the missiles either have characteristics that are identical to or close to those of the ground guidance radar, or they are noise jamming signals with the same frequency as the ground guidance radar signals. Because these missiles are charged with the dual tasks of decoying and hard killing of ARMs, they are called decoying and killing missiles. Figure 1 shows a schematic diagram of a DKM intercepting an ARM.



② 图 1 DKM拦截ARM方案示意图

Key: (1). Radar. (2). Figure 1 Schematic diagram of a DKM intercepting an ARM.

According to the plan set forth in this paper, the physical process of a DKM intercepting an ARM is roughly as follows: acquisition radar acquires an enemy airplane that may be invading and, when it finds that the enemy airplane is actually invading and has entered the sphere of action of the guidance radar, it transmits the position information of the target to the tracking radar. The tracking radar then starts up and begins to capture and track the target. The tracking radar has the functions of sounding an alarm to warn against the airplane that fired the ARM and accurately determining the direction from which the ARM attack is coming. If it detects that an enemy airplane has fired an ARM, the tracking radar immediately gives an alarm and transmits information concerning the ARM to the fire-control system of the DKM which, based on this information, rapidly launches the DKM in the direction of the attacking ARM to intercept it. At

this point, the radar does not immediately shut down, but gradually reduces its radiation power and, when conditions allow, switches over to infrared or television tracking of the launching aircraft. In this way, the ARM continues to close in on the radar by following the radar beam; at the same time, the receiver of its guidance head also receives jamming signals (false radar signals or noise jamming signals from the jammer on the DKM). When the power of the jamming signals received by the guidance head of the ARM is greater than the power of the signals it receives from the real radar, the ARM changes direction to track the DKM, and the radar shuts down. In this way, the missiles intersect in the air. The DKM itself has a fuze and a warhead, and when the missiles intersect, the fuze of the DKM detonates the warhead and destroys the ARM. In unfavorable circumstances where the two missiles cannot intersect well and the amount of miss[a] between the two missiles is rather large, the DKM cannot destroy the ARM. However, because the ARM tracks the DKM for a long period of time and the ground radar shuts off early on, it is not easy for the ARM to change direction and attack the ground radar again.

Because requirements for decoy signals are lowered, and because it is unnecessary for the ground radar to track the ARM continuously, the use of DKMs to counter ARMs is technically relatively easy to achieve. Clearly, there are two key technical aspects to implementation of this anti-ARM plan: one is the sounding of an alarm when the ARM is fired; the other is choosing and setting up a jamming signal in the DKM — that is, finding a way to set up jamming signals to attain the goal of decoying the ARM. These two problems will be specifically addressed in a follow-up paper, and not explained in detail here.

3. A Mathematical Model

To carry out a theoretical proof of the feasibility of this plan for interception of an ARM by a DKM, it is necessary to set up a mathematical model describing the physical process of interception of an ARM by a DKM. Low-to-medium altitude missile weapon systems were used as the background for setup of this model, and HARM was used as the target, in order to strive to make the model setup and simulation work both significant on a practical level and highly advanced.

Figure 2 is a modular structure drawing showing a mathematical model of a DKM

[a] As published. "Miss distance" is probably more appropriate for this paper.

intercepting an ARM. In this model, parameters for the DKM

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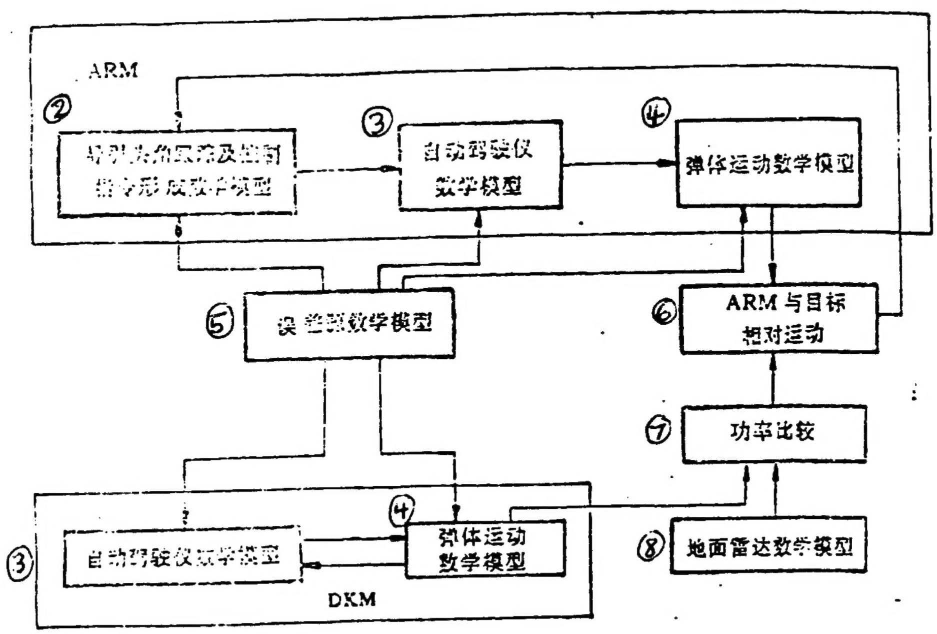
model were taken from a low-to-medium altitude surface-to-air missile; the radar parameters were derived from the guidance radar of a low-to-medium altitude surface-to-air missile system; and the parameters for the jammer on the DKM were selected freely. Determination of the parameters of the ARM is the key to the whole mathematical model. Here, the control system parameters of the ARM were on one hand determined through mathematical simulation, and on the other, [through] consulting the parameters of the Aspide missile, because the Aspide missile and the ARM were both developed from the Sparrow missile.

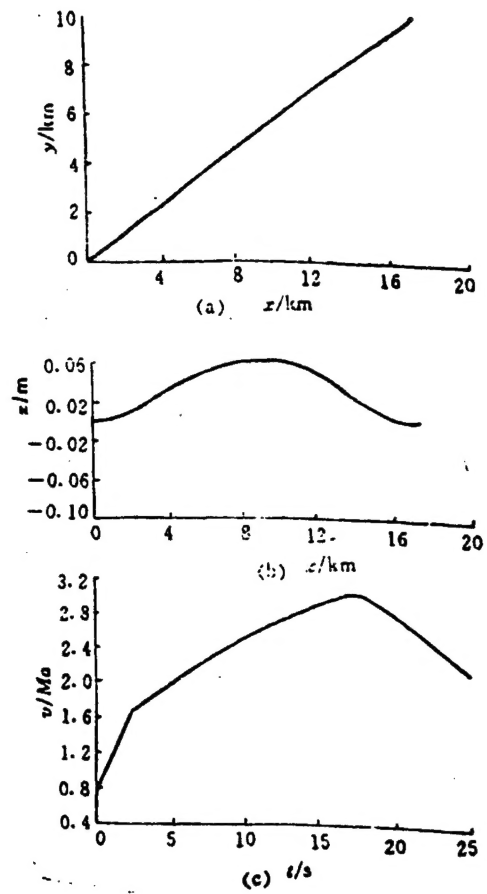


(1) 图 2 数学模型的模块化结构图

Key: (1). Figure 2 Modular structure drawing of mathematical model. (2). Mathematical model formed by guidance head angle tracking and control commands. (3). Autopilot mathematical model. (4). Mathematical model of missile body movement. (5). Mathematical model of error source. (6). Relative motion of ARM and target. (7). Comparison of power. (8). Mathematical

model of ground radar.

4. Mathematical Simulation



(1) 图 3 ARM攻击制导雷达时的运动轨迹和速度随时间变化的曲线

Key: (1). Curves showing changes in motion trajectory and speed of ARM over time when attacking guidance radar.

During this mathematical simulation, amount of miss was used to characterize the killing efficiency of the ARM against ground guidance radar and the efficiency of using DKMs to

intercept ARMs. Calculation of amount of miss was done under two separate conditions: ideal conditions which do not take error into consideration, and conditions which do take error into consideration. The primary sources of error that were considered were: wind, initial aiming error when the missiles were fired, off-center engine thrust, rudders inclined towards zero position, guidance system at zero position, and so on.

First, in carrying out simulations of ARM attacks against ground guidance radar, it was assumed that the ground guidance radar had not yet taken any countermeasures against the ARM. The results of simulations of ARM attacks on ground guidance radars from six different positions and with different initial speeds and angles of attack are listed in Table 1; Figure 3 is a group of curve diagrams showing typical changes over time in motion trajectory and speed

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of an ARM when attacking guidance radar. One can see from the figure that the top speed of the ARM during the attack is greater than Mach 3. This concurs with reports in relevant documents.[3] One can see from the results of the simulation that it is very dangerous for ground radars not to take anti-ARM countermeasures; the HARM model that was set up is feasible. The results obtained by using this model to make a mathematical simulation of a DKM intercepting an ARM are therefore believable.

1 表 1 ARM对雷达攻击的仿真结果

2 序号	3 ARM发射位置及速度				4 无误差	5 有误差	
	x(m)	y(m)	z(m)	v(m/s)	6 脱靶量	7 脱靶量均值	8 脱靶量均方差
1	7500.0	12990.4	0.0	300.0	0.53	0.55	0.19
2	14142.1	14142.1	0.0	300.0	1.84	2.185	0.293
3	17320.5	10000.0	0.0	250.0	3.77	4.33	1.00
4	23492.3	8850.5	0 0	280.0	6.58	7.10	0.277
5	14095.4	5130.3	0.0	250.0	4.77	6.28	1.00
6	19318.5	5176.4	0.0	250.0	11.1	11.33	0.88

9 **表 2　ARM取不同初始位置时的仿真结果**

2 序号	3 ARM发射位置及速度				DKM	4 无误差	5 有误差	
	x(m)	y(m)	z(m)	v(m/s)	θ(rad)	6 脱靶量	7 脱靶量均值	8 脱靶量均方差
1	7500.0	12990.4	0.0	300.0	0.894	1.82	7.42	3.34
2	14142.1	14142.1	0.0	300.0	0.628	3.31	10.62	5.87
3	17320.5	10000.0	0.0	250.0	0.382	1.64	5.28	2.32
4	23492.3	8850.5	0.0	280.0	0.212	3.42	5.31	2.67
5	14095.4	5130.3	0.0	250.0	0.220	3.04	7.66	3.94
6	19318.5	5176.4	0.0	250.0	0.126	1.67	6.19	2.93

诱杀弹初始态：$x=50.0$m，$y=3.0$m，$z=0.0$，$\phi=0.0$，$\gamma=0.0$

11 **表 3　DKM取不同初始位置时的仿真结果**

2 序号	12 DKM初始状态参数					4 无误差	5 有误差	
	x(m)	y(m)	z(m)	ψ(red)	θ(rad)	6 脱靶量	7 脱靶量均值	8 脱靶量均方差
1	50.0	3.0	0.0	0.0	0.382	1.64	5.28	2.32
2	100.0	3.0	0.0	0.0	0.385	1.51	5.44	2.61
3	0.0	3.0	50.0	0.006	0.377	3.33	6.51	3.20
4	0.0	3.0	100.0	0.013	0.377	3.36	6.67	3.18
5	35.36	3.0	35.36	0.01	0.378	4.66	7.54	3.60
6	70.7	3.0	70.7	0.012	0.383	2.05	7.69	2.80
7	-50.0	3.0	0.0	0.0	0.374	4.40	7.28	3.22
8	-100.0	3.0	0.0	0.0	0.373	3.62	6.46	2.78

13 ARM初始态：$x=50.0$m，$y=3.0$m，$z=0.0$，$v_x=250$m/s，$v_y=v_z=0$

Key: (1). Table 1 Results of Simulation of ARM Attack on Radar. (2). Sequential numbering. (3). Position and speed of ARM firing. (4). Without error. (5). With error. (6). Amount of miss. (7). Mean amount of miss. (8). Mean square error of miss. (9). Table 2 Results of Simulation of ARM at Different Initial Positions. (10). Initial state of DKM:(...) (11). Table 3 Results of Simulation of DKM at Different Initial Positions. (12). Parameters of DKM initial

states. (13). Initial state of ARM:(...)

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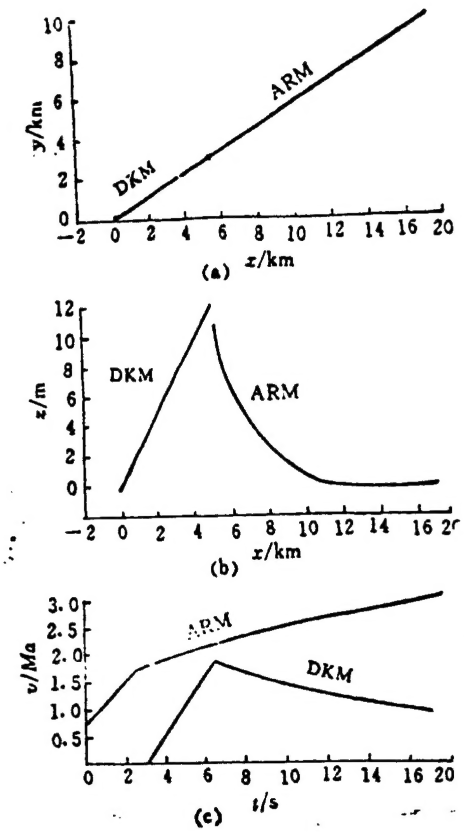

(1) 图 4 ARM与DKM的交会轨迹和速度

ARM: $x=17320.5m$, $y=10000.0m$, $z=0$, $v=250m/s$;

DKM: $x=-100.0m$, $y=3.0m$, $z=0$, $\phi=0$, $\theta=0.373rad$.

Key: (1). Figure 4 Intersection trajectory and speed of ARM and DKM

Afterwards, simulation calculations of the physical process of interception of ARMs by DKMs were carried out. The simulation primarily centered on the effects of seven factors on

the intersection of the two missiles. These seven factors were: ARM firing position, ARM firing speed, DKM deployment position, DKM reaction time, jammer beam width, ground radar shutdown time, and wind speed. The amounts of miss obtained in the simulations were all within 10 meters. This shows that DKMs can carry out effective kill against ARMs. The results of simulations in two different situations are listed in Tables 2 and 3. Figure 4 is a set of curve diagrams [depicting] the changes over time in motion trajectory and speed of the two missiles during the process of intersection.

5. Conclusions

The use of DKMs to counter ARMs evades the technical difficulties of hard kill and decoy anti-ARM schemes, represents a novel way of thinking, is based on simple and clear principles, and is not difficult to implement. Initial mathematical simulations prove that this plan is feasible in principle. It should be pointed out that the work done for this article is just a beginning for decoy-killing as a new kind of anti-ARM technology. Future work should include the following: on one hand, implementing more profound theoretical research to further perfect this plan; and on the other hand, carrying out relevant partial-scale and full-scale simulation research.

(Acknowledgements: We wish to express our deepest gratitude to Messrs. Zhang Hairong and Liang Junyi and Ms. Shen Jie of the Eighth Design Department of the Shanghai Academy of Spaceflight Technology for their help and guidance in model setup and simulation calculations for this article.)

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MATHEMATICAL SIMULATION OF COUNTERING ANTI-RADIATION MISSILE BY USING DECOYIGN & KILLING MISSILE

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(The 8th Design Department of Shanghai Academy of Spaceflight Technology)

Abstract A new method of countering anti-radiation missile(ARM) by using decoying & Killing missile (DKM) which is actually a surface to air missile except its guidance-head being replaced with a decoying jammer is proposed in this paper. Simulation is carried out on basis of the mathematical of intercepting ARM with DKM. Simulation results are also given to verify this method theoretically.

Keywords Anti-radiation missile (ARM), Decoying & killing missile (DKM), Mathematical model, Simulation

Key: (1). Continued from Page 7